

Advanced Approach to Concept and Design Studies for Space Missions¹

MarieJose Deutsch

Mission and Systems Architecture
Jet Propulsion Laboratory, California Institute of Technology²

and

Joy S. Nichols

Chandra X-Ray Center
Harvard-Smithsonian Astrophysical Observatory³

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²MS 264-767, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
Mariejose.C.Deutsch@jpl.nasa.gov

³60 Garden St., Cambridge, MA 02138, USA, *jnichols@cfa.harvard.edu*

Abstract

Recent automated and advanced techniques developed at JPL have created a streamlined and fast-track approach to initial mission conceptualization and system architecture design, answering the need for rapid turnaround of trade studies for potential proposers, as well as mission and instrument study groups. JPL has assembled a team of multidisciplinary experts with corporate knowledge of space mission and instrument development. The advanced Concept Design Team, known as Team X, provides interactive design trades including cost as a design parameter, and advanced visualization for pre-Phase A mission feasibility studies. The proposer and Team X collaborate closely in developing scenarios, and Team X responds with a detailed integrated mission/instrument design and development plan within 1 week. Iteration of the plan is on a similar rapid turnaround basis. JPL has experience planning more than 250 missions, including pointed and survey astrophysics missions such as GALEX, SIM, IRAS, SIRTf, and WIRE.

1 Introduction

One of the most time-consuming and difficult processes in developing plans for a new mission is designing the spacecraft, instruments, orbit, and ground systems to the level required to create a viable proposal, while keeping the science objectives foremost in the design. The most efficient and scientifically rewarding approach is to have the science team interactively making trade-off decisions during this early design phase, with rapid turn-around of full system design with each trade-off proposal. In the past, the system design was an extended, fragmented process with limited possibility of evaluating the effect of each design decision on the entire mission. Early designs tended to be of low fidelity, increasing the cost and time of the mission design phases. In recent years, funding for science missions has been sharply constrained and a more efficient and less costly method of developing high fidelity, customized mission designs is an important component on the path to a successful mission.

2 Mission Design Services

2.1 Focused Environment

Team X is a standing team, composed of top experts in their fields, chosen for their extensive experience, their expert knowledge in advanced technology, and their creative thinking. The team is composed of 15 different design elements ranging from spacecraft and instrument designers to launch vehicle, trajectory, and orbit, ground system, mission planning and costing experts. The team works in a real-time environment conducive to a highly interactive working situation. The principal investigator or science study team leader becomes part of the design team meeting in the Project Design Center at JPL to scope out a mission. As the design of the mission takes shape, it is assessed against cost, schedule, and risk factors. Team X works interactively and iteratively with the proposer, providing information and suggestions, allowing the science study team to change guidelines and evolve the design into a feasible mission concept.

2.2 Concurrent Engineering

The traditional process of designing all aspects of a mission consecutively has been replaced by a method of concurrent engineering. As the requirements

are reflected into the design of the spacecraft and instruments, the results on mass, power, and launch vehicle capabilities can be readily seen. In turn, impacts to schedule, cost, and risk become apparent. Concurrent trades between hardware, software, ground system, orbit, schedule, risk, cost, and science requirements are preformed, leading to multiple design options and ultimately the most feasible option in 1 to 3 weeks turnaround time. As an example, a requirement for new technology development can lead to "roadmap" proposals with specific recommendations for successive technology validations before the basic mission can be flown. Cost, risk, and schedule for roadmaps can then be compared to more conventional designs, making use of existing technology possibly deployed in new ways or near-term technology challenges. Concurrent engineering can also be used during the evaluation process of an existing proposal (2-3 days) and provide the science team with feedback on weak points in the proposed design and recommendations for improvements.

The mission parameters are agreed upon by working with the science team prior to Team X design activities. The parameters considered in the design trade space are:

1. the study objectives
2. programmatics associated with the potential mission, such as institutions involved, international partnerships, and constraints on schedule and cost
3. the science objectives, measurement objectives, and data collection scenario
4. mission characteristics, such as trajectory, launch date, desired orbit, mission duration, and preferred launch vehicle
5. instrument requirements, such as instrument type, mass, size, power, sensitivity, resolution, spectral dispersion, data storage, processing speed, output data types and rates
6. in-flight reprogramming parameters, such as deployment, pointing control, contamination, thermal interfaces, and inheritance
7. field-of-view requirements, pointing control, pointing knowledge, reconstruction requirement
8. ground system requirements

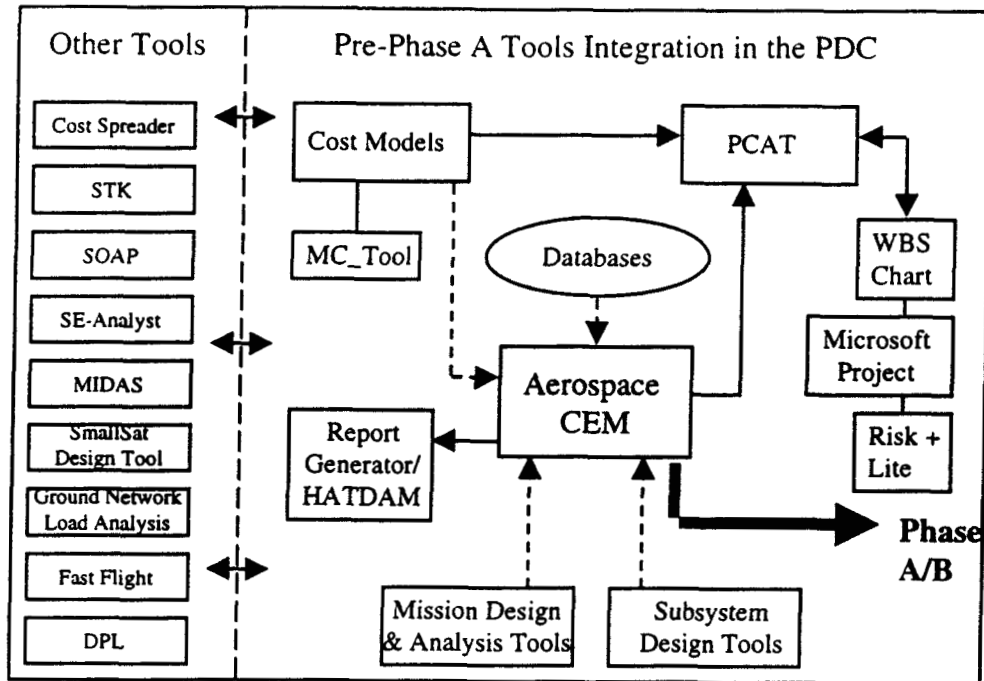


Figure 1: Software tools used by Team X

9. telecom system requirements

2.3 Instrument Design

A similar and parallel process is planned for the design of instruments. The Advanced Instrument Concept Design Team (Team I), spins off its own but similar process. The results of this study are then folded back into the overall trade study. The Team I concept is currently under development.

2.4 Tools for designing to cost and for optimization and trade-off studies

The concurrent engineering process is supported by a software set of subsystem-specific and system level integration tools (Fig. 1). The Aerospace Concurrent Engineering Methodology (CEM) is a set of linked spreadsheets which facilitate data sharing between mission design and analysis tools, subsystem design tools, and cost models. Each subsystem of the distributed CEM developed at JPL uses its own design tools and cost models, which are

then linked with all other subsystems. This methodology allows for detailed bottom-up subsystem design and costing giving the science study team a higher level of detail and fidelity. The design is costed using at least two of three different models: the Project Cost Analysis Tool (accepts input from CEM), the Stochastic Costing Tool, and the Requirements-based Operations Cost Model. The process also applies additional judgment to these numbers taking into account special circumstances such as a international partnerships and other programmatic issues. For further details on the tools used by Team X, refer to <http://pdc.jpl.nasa.gov>.

3 Benefits to science of new mission design approach

The design of a new mission benefits greatly from the integration of the science team in the early mission trade studies. The science team is uniquely capable of deciding what features or goals to sacrifice and what features or goals to retain in order to propose a mission that will be able to achieve the science needed. For example, a science goal might be to fly a telescope of 5m aperture. However, Team X would find that there is no existing launch vehicle to accommodate this size. A trade-off that suggested a folding mirror would be identified as new technology with a large amount of risk. Alternate strategies that would be evaluated might include the development of a larger launch vehicle, higher sensitivity for the instruments to mitigate a somewhat smaller aperture, or interferometry. If the science team is present when these ideas are evaluated, the design will ultimately be the most feasible for the cost and science goals.

The overall-goal of the early mission design is to maximize performance, and minimize cost and development time (Figure 2). Each of these parameters is driven by multi-parameter dependencies which can best be evaluated in concert by the science team, co-located with spacecraft system experts.

The rapid approach to mission high-level design described above is available as a service to science teams who are preparing to formulate ideas for space missions into proposals for funding for the missions. The difficulty of seeing and evaluating the effect of changes in the design has been largely overcome with the interactive environment available at Team X. More importantly, the time required to progress from an idea for a science mission to high-level mission design of the full system is 1 day of interactive work with the science team and approximately one week to fully document the

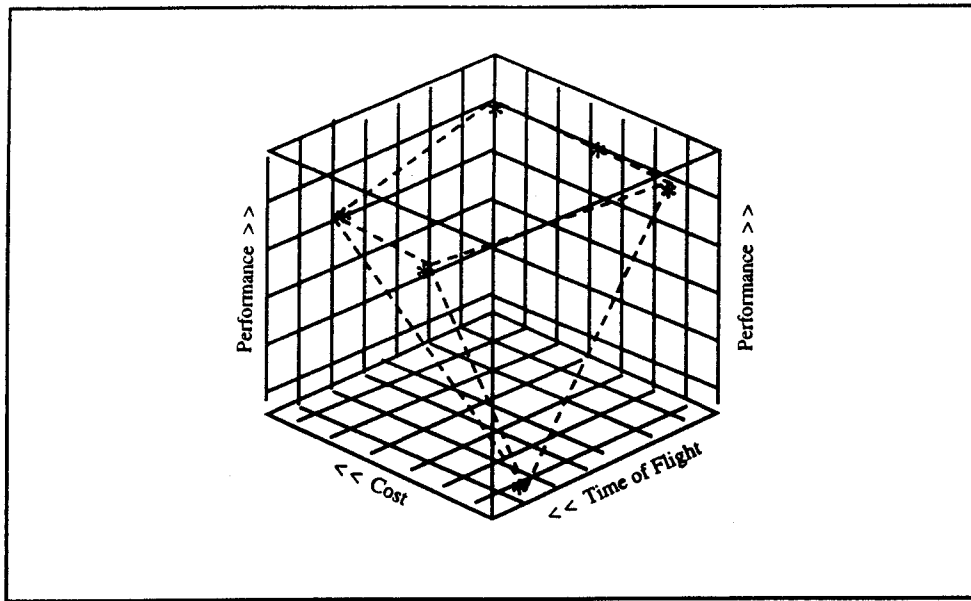


Figure 2: Mission Design Trade Space: This diagram represents how design teams think of "trade space" - the conceptual volume wherein design options are manipulated. Hundreds of interacting factors contribute to the positions of the points, which ultimately guide the trade-off decisions.

results.

The products available from Team X to the science team include:

1. Orbit specifications
2. Launch vehicle specifications
3. Cadcam design of spacecraft to provide science functionality
4. On-board mass, electrical, thermal design
5. Design of ground system and downlink plan
6. Identification of new technology and other risk factors
7. Cost of each element; resources required; schedules for development phases
8. Documentation of trade-offs evaluated by science team, including all rejected plans

The products provided to the science team at the conclusion of a Team X session are sufficient to present in a proposal for a space science mission

to convince the funding agency that the mission is feasible and responsibly costed.

Team X has supported more than 250 missions with either the generation of complete design specifications or with review of existing designs. The computer-aided tools are constantly being updated to benefit from JPL experience and expertise. The "design to cost" methodology is also constantly refined and updated to provide the most accurate estimate possible.

4 Limited Study

In order to optimize the potential return from a mission design study with Team X, the science proposers must have very well defined science goals. The instrument capabilities must also be defined and consistent with the science goals. Lastly, the cost ceiling is an important design driver. Many proposers do not have their science goals clearly defined at the outset of a mission design study. For this reason an alternate option is offered, which is more focused on specific aspects of the mission and involves a smaller team (Team A) over a shorter time frame of a day or two. The design products are negotiable but are also more limited. As an example, such an approach might be used for a study focused on organizing initial ideas into a first cut mission concept and overall feasibility study. This step will help bring attention to areas that will need further definition and decision making before a more indepth mission study can be undertaken. A case in point is the World Space Observatory, endorsed during the 8th UN/ESA Workshope, which could use the output of such a feasibility study to gather further support and momentum.

5 Acknowledgements

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